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Real Time Image Haze Removal on Multi-core DSP

Linting Bai[a,b,c,d,] *, Yongwei Wu[a,b], Jianchun Xie[c,d], Pengcheng Wen[c,d]

[a]*Department of Computer Science and Technology, Tsinghua National Laboratory for Information Science and Technology(TNLIST), Tsinghua University, Beijing 100084, China*

[b]*Technology Innovation Center at Yinzhou, Yangtze Delta Region Institute of Tsinghua University, 315100, ZheJiang*

[c]*AVIC Computing Technique Research Institute, No.15, Jinye 2 steet, Yanta District, Xi'an 710065, China*

[d]*Aviation Key Laboratory of Science and Technology on Airborne and Missleborne Conputer, No.15, Jinye2 street, Yanta District, Xi'an, 710065, China*

Abstract

The quality and visual effect of an image is high demanded in avionic embedded field. But the frog and haze is common in the nature environment, so foggy images gathered in bad weather need to be disposed to remove the haze. The single image haze removal algorithm using dark channel prior can achieve great haze removal effect, but the process of optimizing the medium transmission in this algorithm costs too much time, while the computational complexity is too high to be real-time operating for high resolution image. In this paper, a novel method is proposed which uses a new kind of filter called guided filter to optimize the medium transmission. This method is much faster and also can achieve good haze removal effect. In addition, the method uses down sampling and interpolation method to transform a high resolution image into a low one to reduce the quantity of calculation. At last, we implement the novel algorithm on a multi-core DSP of TI company. The experimental results show that the method costs less than 40ms for a 600*400 resolution image and can satisfy the demand of real-time image process.

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* Corresponding author. Tel.: +86-13259723174, +86-029-89186500
E-mail address: blt.thisislife@gmail.com

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1. Introduction

Image processing is widely used in airborne embedded field. Like The Enhanced Vision System (EVS), Synthetic Vision System (SVS) and Enhanced Flight Vision System (EFVS) which are widely used in the cockpit system, the cockpit display shows images gathered by airborne sensor real-time, it is expected that the images are legible and recognizable. However, outdoor images are usually degraded by the bad weather, such as frog, haze, smoke, and so on. So the blurry images should be disposed to be legible before being shown on the display and this process is called image haze removal. As a research hotspot in computer vision field, image haze removal methods are widely desired in many applications, e.g. monitoring, object detecting and tracking, or artificial intelligence, wherein embedded processors are the major processors, such as DSP and FPGA. So the real time image haze removal method which was adapted in such embedded systems should be discussed.

2. Summary of Image Haze Removal

According to whether the process of haze removal is based on physical model: physical based (MB) and non physical based (NMB) [1]，there are two kinds of haze removal methods. Physical based methods are based on the atmosphere transmission model (ATM),which analyze the factors that can influence the quality of image through atmosphere, and recover the image by inversing the transmission process. There is no exact solution to this model as there are three unknown parameters, so assumptions and approximations are added to solve the model [5, 6, 7] or multi images of the same scene are used to help solving it [2, 3, 4]. Methods using assumptions or approximations deal with a single image, estimating the parameters in the ATM by adding assumed conditions or prior information. Tan [5] observes that the contrast of haze-free images is much higher than haze images by analyzing a lot of outdoor images, so they remove the haze by maximizing the local contrast of haze images. This method could achieve good visual effect, but it doesn't recover the real scene contrast according to the ATM, so the results may be over-saturated and unnatural. Fattal [6] assumes that the medium transmission and the shadow on the surface of a scene are uncorrelated, so they estimate the albedo of the scene to solve the medium transmission. This method is based on the statistical information, and can achieve impressive results, but it can't handle heavy haze, and will cause bad effect when there is not enough statistical information as well. He[7] observes a lot of haze-free outdoor images, and draws a conclusion that for a haze-free outdoor image, in at least one channel of RGB color channels, most local patches contain some pixels which have very low intensity. This observation is called dark channel prior. Based on this assumption, the medium transmission could be estimated by minimizing pixels in local patches. This approach could achieve great effect for most outdoor images, while the dark channel prior will be invalid when the scene is similar with the sky.

Non physical based methods don't care the process that image transmitting in atmosphere medium, on the contrary, they remove haze through image enhancement or subjective visual feeling. There are many traditional image enhancing methods such as logarithmic transformation, power transformation, histogram equalization, and spatial filter; or low-pass filter, high-pass filter, and homomorphic filter in frequency domain. Other methods of subjective visual feelings are mostly based on the color constancy theory, such as the Retinex theory by Land [8,9], the improved single scalar Retinex (SSR) [10], multi scale Retinex (MSR) [11], and multi scale Retinex with color restoration (MSRCR) [12,13].

Within all the methods as shown above, the ones based on physical model which can achieve impressive effect relying on the validity of physical model and rationality of assumption are highly researched in recent years . Among them, the method [7] based on dark channel prior could achieve great effect even the haze is heavy, thus is very suited to airborne embedded field. But the most disadvantage of this method is that it costs too much time to satisfy the demand of real-time. To solve this problem, a new kind of fast haze removal approach is proposed in this paper.

3. The Dark Channel Prior

The atmosphere transmission model that is widely used in computer vision and computer graphics field is described as follow:

$$\mathrm{I(x)} = \mathrm{J(x)t(x)} + A(1 - t(x)) \quad (1)$$

Here, I(x) is the intensity of pixel x in haze image I, and J(x) is the intensity of haze free image J, t is the medium transmission which describes the part of light captured by camera, A is the sky light in the scene. The first item of the right-hand side is called direct attenuation, which shows the radiation of scene and its attenuation in medium, and the second item is called air light, which is caused by atmosphere scattering.

As is described above, the dark channel prior is:

$$J^{dark}(x) = \min_{y \in \Omega(x)} (\min_{c \in (r,g,b)} J^c(y)) \quad (2)$$

Here, is channel c of RGB channels in pixel x of J, is the local patch of pixel x. When J is a haze-free image, for most of the local patches excepting for the sky region, the is close to zero. Given another assumption that changes little in , which can be set to be a constant number , we have:

$$\min_c (\min_{y \in \Omega(x)} (\frac{I^c(y)}{A^c})) = \tilde{t}(x) \min_c (\min_{y \in \Omega(x)} (\frac{J^c(y)}{A^c})) + (1 - \tilde{t}(x)) \quad (3)$$

As is positive, the first item of the right hand side is close to zero, so can be estimated. To keep the scene to be natural, a constant parameter is introduced:

$$\tilde{t}(x) = 1 - \omega \min_c (\min_{y \in \Omega(x)} (\frac{I^c(y)}{A^c})) \quad (4)$$

The sky light A could be estimated to be the intensity of the brightest pixel in I, then could be obtained. Finally, substituted these two parameters into formula (1), the haze free image J could be obtained. A lower bound t0 is introduced to avoid from being too small, which would leading J to be noisy. The finally haze free image J is shown as follow:

$$J(x) = \frac{I(x) - A}{\max(\tilde{t}(x), t_0)} + A \quad (5)$$

Using formula (5), we can gain a haze free image, but in this process of haze removal, there is a great error in the step to get the medium transmission , because the assumption to calculate would cause block effect. So the estimated should be optimized. The algorithm in [7] used soft matting and achieved very good effect, but this method is in fact a very complex process of solving a large sparse matrix, and the space and time complexities are too high to be real time. So researching alternate methods for practical applications is highly demanded.

4. Real Time Haze Removal Algorithm

In this paper, an improved real time image haze removal algorithm is proposed to solve the problem of space and time overhead in soft matting. What's more, to achieve the purpose of real time, the parallel processing capability of multi-core DSP is used. The process of our algorithm is shown in Fig. 1.

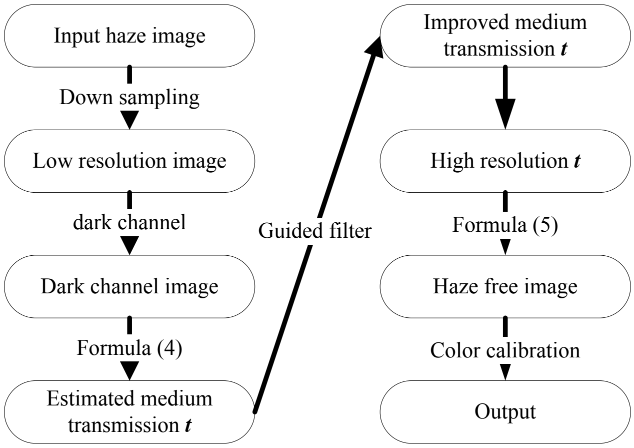

Fig. 1.the real time haze removal algorithm

First, we transform an input high resolution haze image into a low one using down sampling, therefore dark channel image is obtained. Based on the dark channel prior, the estimated medium transmission is then gained, and after this, we use guided filter substituting soft matting to optimize the medium transmission. At last a simple up sampling method is used to recover the high resolution output haze free image. The intensity of the recovered haze free image after this method is a little low, so we use a color calibration method at last to recover the intensity.

4.1. Down Sample

For a high resolution image, the down sampling method can decrease the number of pixels, which could save much processing time. The key point in this step is to choose an appropriate sample percentage to balance the time saved in the process of follow-up steps and the time cost in the process of image down sampling and up sampling.

4.2. Dark Channel

The process of calculating dark channel is shown as formula (2), for which the key computing is running min filter. Using a patch of w*w size to implement min filter for an image of M*N pixels, the most simple traversal method would cost O(M*N*w*w) time.

It has been proved that to perform the running min filter for a linear array, there would be at least 1.5 compares for each pixel in the worst situation. That is, the running min filter for a linear array of N elements would cost at least O(N*1.5) time. Daniel Lemire [12] proposed an algorithm called streaming maximum-minimum filter (SMMF), which would cost no more than three compares for each element when performing maximum-minimum filter for a linear array. Based on SMMF, the algorithm of running min filter for a matrix D is shown in Fig. 2.

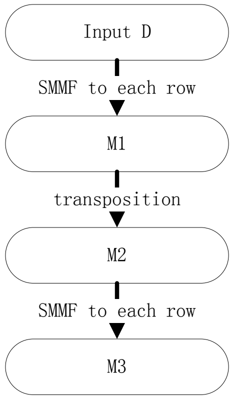

Fig. 2.the real time haze removal algorithm

After this process, for a pixel p at position (x,y) in matrix D, the min filter of its w*w patch is stored at the position (x-w, y-w) in M3.

4.3. Guided Filter

The algorithm in [7] used soft matting to optimize the medium transmission , which would cost much time and space. To address this disadvantage, a lot of alternate methods have been proposed. Kang Sun [15] uses bilateral filter to estimate the local mean value and standard deviation, and the atmospheric veil is then estimated. He [14] proposes a novel image filter called guided filter. By considering a guidance image, which could be the input color image or its one channel, the guided filter could optimize the medium transmission. The key computation of guided filter is mean filter, which could be implemented by fast mean filter algorithm. Considering the spatial locality of mean filter, which is appropriate for parallel computing, we use guided filter to replace soft matting to optimize the medium transmission.

The algorithm of guided filter is shown in Fig. 3.

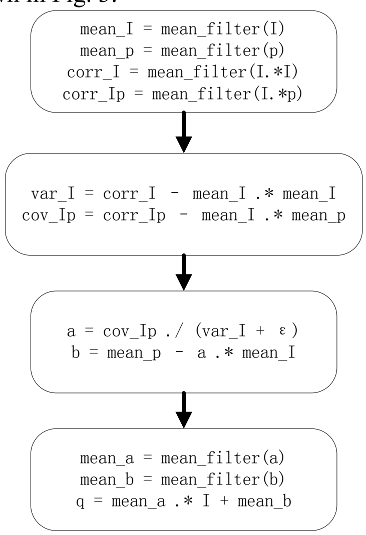

Fig. 3.the algorithm of guided filter

Here, p is the input image, I is the guidance image, and p is the output image. In this algorithm, the function mean_filter() is the mean filter of an image, which could be computed in O(N) time by moving sum[14], where N is the number of pixels.

4.4. Up Sample

The high resolution medium transmission ***t*** is recovered by up sampling. The most common methods of upsampling are based on interpolation, such as bilinear interpolation, bicubic interpolation, and spline interpolation. These methods are fast and simple to implement, but they would produce blurry results when the up sampling factor is large. Other example-based methods learn information from a set of images; these methods could achieve great effect, with the cost of expensive computation. Qi Shan [15] proposed a novel fast single image up sampling method based on a de-convolution and re-convolution model, which could achieve great effect.

Considering the factor of up sampling and the demand of real-time, we use bilinear interpolation to up sample the medium transmission.

4.5. Color Calibration

The output haze free image would have very low global intensity after all above steps, and the contrast would be low too, so there is a demand to calibrate the intensity, contrast and color. The histogram scratch is a simple and effective method to increase contrast and is appropriate for real time applications. So we use histogram scratch[16] to calibrate color. The formula is shown as follow:

$$Out_c(x,y) = \frac{In_c(x,y) - Min(In_c)/\omega}{\omega Max(In_c) - Min(In_c)/\omega} MAX\_VAL \tag{6}$$

Here, is channel c of input image In, and are the maximum and minimum of channel c of In, and MAX_VAL is the max intensity of channel c in output image, which is set to 255 to maximize the contrast. In the fact, pixels with intensity close to or are usually little, so we added a parameter ω(0<ω<1) to adjust the max and min intensity.

4.6. Parallel Optimization on Multi-core DSP

Digital Single Processor (DSP) is a kind of application specific processor of which the architecture and instruction set are optimized for digital single processing. It is very appropriate for embedded image processing system with the advantage of fast computation speed, low power consumption, plenty of complex instructions, and so on. Specially, multi-core DSPs are capable of parallel processing with two or more DSP cores, which is very suitable to deal with image processing. The Texas Instruments (TI) company has produced a series of multi-core DSPs since 2007, and until now, the TMS320C6678 development board is the most advanced processor with the most DSP cores and the highest performance. This board has 8 C66x DSP cores with 1.25GHz for each, along with 4M shared L2 SRAM and 2GB DDR3 memory with totally access permission to all cores. Besides, C6678 supports Inter Processor Communication (IPC), Direct Memory Access (DMA), OpenMP, and so on, which are useful in parallel processing.

In this paper, we implemented parallel optimization through APIs of OpenMP under the Code Composer Studio (CCS) development environment. Most computation in our algorithm is the min filter in dark channel step and the mean filter in guided filter step. In the process of dark channel, the min filter of each row is independent, so the computation can be paralleled into different cores using a compiling optimizing instruction "#pragma omp parallel for". In the process of guided filter, the computation in each step in figure 3 is independent, and the data is shared. So we deal with each step in parallel and put the data in L2 SRAM. Another compiling optimizing instruction is used: "#pragma omp parallel section".

5. Experiment Results

In our experiments, the factor of down sampling was set to be 2 for an input haze image with resolution less than 600*600, and 3 for higher; the patch size was set to be 15*15 in dark channel; the patch size in guided filter was set to be 30 or higher, and the min of RGB channels was used as guidance image. Then we implemented our algorithm with c code under the CCS development environment.

Fig. 4. the result of algorithm in [7] and our algorithm. Left: input image. Middle: [7]'s result. Right: our result

Fig. 4 is the result of algorithm in [7] and our algorithm. It can be seen that the results of these two methods are both impressive, especially the intensity and definition. This indicates that our method of optimizing the medium transmission is effective, the factor in down sampling and up sampling is reasonable, and the interpolation method is effective. Moreover, the result of [7]'s method is more distinct than our method, but the image is too dark, and the degree of haze is the same for the scene of the vicinity and the distance, which is incongruent with the natural environment. On the contrast, the result of our method is brighter, and the scene in the distance reserves some haze, which indicates the perspective effect.

Table 1. some metrics of images in Fig. 4.

	Input image	Result of [7]	Result of our method
Mean	144.6	64.6678	137.4140
Variance	491.2272	2594.7	2950.9
Entropy	4.4392	5.0324	4.8195
Time	/	19.2s	0.047s

Table1 shows some metrics of the results in figure (4), including mean, variance, entropy, and execution time. From the number of mean we can see that the mean of our method is more close to 128, around which our eyes could distinguish more exact intensity. The variance of our method is the highest, which indicates that the contrast of our result is the biggest. The entropy of our result is much higher than the input image, which shows that our result has much more detail information than the input image, but the entropy of our result is less than that of [7]'s result, which is one of our disadvantage. At last, the execution time of our method is much less than that of [7]'s method, and the most important is that it is less than 50ms, which means that our method can deal with video data real time.

Figure 5 shows some other examples of our algorithm. All the results are effective, which means that our method is appropriate to many applications.

Fig. 5. other examples of our algorithm.

6. Conclusions

In this paper, we proposed a novel real time haze removal algorithm. Based on the dark channel prior, with the help of down sampling and guided filter. Compared to [7]'s method, our method is much faster, which means the method is very suitable for most avionic real time applications.

The disadvantage of our method is that the method of up sampling is too simple, which would influence the contrast of output haze free image. This should be our further research point in this field.

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